The Ocean-Carbon Connection

Summary

Grade Level: 10 - 12

Teaching Time: 40 minutes

Activities:

- **Examine graphs to examine changes in pH, sea-surface temperature, and dissolved CO_2 within the study area.**
- **Correlate changes in pH to changes in CO_2 over time.**

Vocabulary

carbon cycle – the recycling of organic and inorganic carbon as it moves between Earth's biosphere, geosphere, hydrosphere, and atmosphere.

carbonic acid – a weak acid H_2CO_3 formed when carbon dioxide dissolves in water.

Objective

Students will use online tools to access data graphs of ocean pH, sea-surface temperature, and CO_2 data to find the driving factor behind ocean acidification.

Background

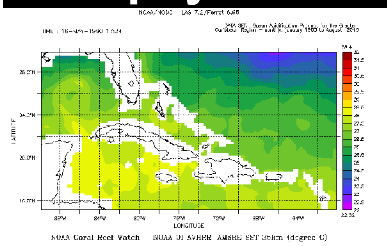
Carbon is essential to life on Earth. Carbon is a component of the tissues of both animals and plants. When animals breathe, they exhale carbon dioxide (CO_2) into the atmosphere or the water. When plants respire, they take in CO_2.

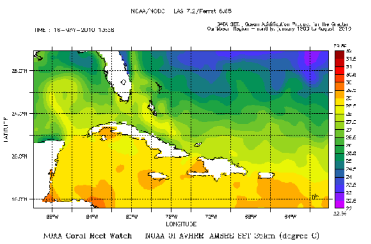
Carbon is stored in various reservoirs within the Earth system. Rocks store carbon. Soil stores carbon. Earth's living organisms store carbon, as does Earth's atmosphere and its ocean. However, that carbon does not stay in one place. As part of the carbon cycle, these reservoirs can either add carbon to the atmosphere or remove carbon from the atmosphere. Ideally, the amount of carbon moving into and out of the atmosphere would cancel each other out and overall levels would remain stable.

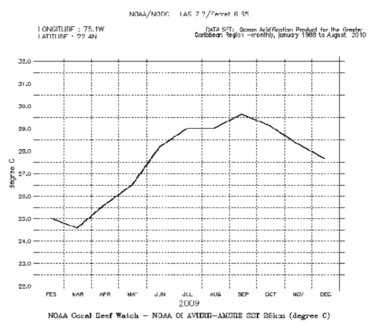
Human activity currently ensures that there is an excess of carbon moving through the cycle. Due to deforestation and modern industrial society's use of fossil fuels, humans currently add more carbon to Earth's atmosphere in the form of CO_2 than can be taken out of the atmosphere by natural processes. Earth's ocean is one such carbon sink. The ocean absorbs approximately one-third of the CO_2 released into the atmosphere from human activities.

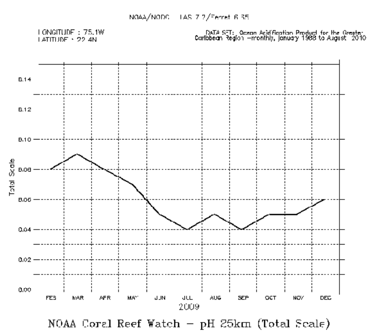
As CO_2 dissolves in seawater, the pH of the seawater decreases. The water becomes less alkaline. This process is called "ocean acidification." Because of the burning of fossil fuels since the start of the Industrial Age (around 1880), Earth's ocean is experiencing a drastic or rapid change in pH. Many ocean ecosystems may be unable to adapt to this change in ocean pH.

To Display









Generate these images at www.dataintheclassroom.org

Preparation

If you have access to a computer and projector, you can display sea-surface temperature and pH time series graphs you create online. Use the following steps:

1. Visit www.dataintheclassroom.org and click on the Ocean Acidification module link.

2. To access the data area for the Ocean Acidification module, select the "Get Data" link at the bottom of the left menu.

3. First you will create two sea-surface temperature (SST) maps for the entire study area in the Caribbean. In future data sets, you will be able to select a portion of the study are using the "Select a region" part of the screen. For now, leave this set for the default area.

4. Select "Sea surface temperature" in the "Which parameter?" pulldown.

5. Next select "Map" on the menu labeled "Which view?"

6. Specify the date by changing the date input to "May 1990."

7. Select "Image" on the menu labeled "Select an output format."

8. Finally, click the "Get Data" button. A new browser window will open that contains the SST map image you requested.

9. You may now save the SST map image to your local computer for later use. On a PC, right-click on the map with your mouse, select "Save Image as…" and provide a file name and local save

destination. On a Mac, hold down the Ctrl key and click with the mouse. When you have finished saving the map image, you may close that browser window.

10. Now create the second sea-surface temperature map. Change the date input to “May 2010” and click the “Get Data” button. Save the second SST map image to your local computer. When you have finished saving the map image, you may close that browser window.

11. Next you will create time-series graphs. The first graph will show changes in sea-surface temperature over time for a point location in the middle of the default study area. You do not need to change the parameter or output format selections.

12. First, change from “Map” to “Time series graph” on the menu labeled “Which view?”

13. Change the date inputs to “January 1988” and “August 2010.”

14. Click the “Get Data” button. A new browser window will open that contains the time-series graph image you requested. This graph shows changes in sea-surface temperature from 1988 to 2010 for a location at the center of default geographic area. When you have finished saving the graph image, you may close that browser window.

15. Now create the second time series graph. This graph will show changes in pH from 1988 to 2010 for the same point location as the SST time series graph.

16. Select “pH” in the “Which parameter?” pulldown. You do not need to change the view or output format selections. Make sure that the date inputs are still set to “January 1988” and “August 2010.”

Take Note

Carbon Cycle Complexities

There are many factors that affect global, regional, and local transfer of carbon dioxide from the atmosphere to the ocean or vice-versa. Point sources (e.g., a large coal-burning power plant near the coast) may raise CO_2 in the atmosphere over the ocean locally, but that CO_2 is not tied to one location. The CO_2 disperses and gets spread out by air movements. Wind can also increase gas transfer from the atmosphere to the water. Bubbles formed in breaking waves can increase local transfer of CO_2 into the water. Photosynthetic marine organisms, such as an algal bloom, can use large amounts of CO_2 to grow and then store carbon in their cells until they decay.

17. Click the “Get Data” button. A new browser window will open that contains the pH time-series graph image you requested. When you have finished saving the second graph image, you may close that browser window.

18. Finally, create two more time-series graphs. This time, limit the time to the year 2009 by choosing “January 2009” and “December 2009” for the date inputs. Create a time-series graph for pH and another one for sea-surface temperature for this time period. Save the two graph images.

Materials

- **Computer or overhead projector**
- **Map and graph image(s) saved to your computer**
- **(for demo) container of tap water, blue pH indicator, small piece of dry ice or a straw**
- **Copies of Student Master**

Procedure

Now that you have the images, you can either show them from your computer if it is connected to a projector, or make transparencies of the images for display using an overhead projector. You may also choose to create maps or graphs in real time so that students see how to use the data access area of the module.

1. Show students the time-series graph that displays pH change in the area from 1988 to 2010. Explain the key features of the graph:
   - X axis = time in years
   - Y axis = pH
   - Students should also notice that the graph is for a single latitude/longitude location. This location is in the center of the geographic area specified when creating the graph.

2. The pH of ocean water is around 8.1, which is slightly basic. Students should know that lower pH values represent less alkalinity (and thereby more acidity). Discuss these questions with your students: *For this time period, has the water become more acidic or more basic? What do the regular pH increases and decreases each year represent?* Students should notice that pH has decreased gradually over the 22 year time period. Students should also notice that there is a seasonal effect each year, with pH being lower (seawater less alkaline) toward the end of summer.

3. Ask students what they would expect to find if they looked at a graph of pH change over a single year. Then show your students the time-series graph of pH for 2009.

4. Ask students what they would expect to find if they looked at a graph of sea-surface temperature (SST) over the same year. Then show your students the time-series graph of SST for 2009. If possible, show the two graphs (2009 pH and SST) side-by-side for easy comparison. *How do the two graphs correlate?* Students should notice that these two graphs are inversely proportional. As surface water temperature increases, pH decreases.

5. Discuss these questions with your students: *If every year shows the same seasonal effect on pH, why is the overall pH trending downward (i.e., less alkaline ocean) over time? What do you expect to see if you looked at a time series graph of sea-surface temperature for the longer, 1988 to 2010 time period?* Student answers to both questions will vary. Students are shown the 1988 to 2010 SST time series graph in the Student Master and will see that sea surface temperature is gradually increasing over time.

6. Show your students the time-series graph of SST for 1988 to 2010. If possible, show this graph side-by-side with the 1988 to 2010 pH graph. *How do the two graphs correlate? Do you think changes in sea-surface temperature are responsible for the long-term increase in ocean surface water acidity?* Students should notice that these two graphs are inversely proportional. As surface water temperature increases, pH decreases. However, this does not mean there is a cause-and-effect relation between the two factors. As they work through this and later activities, students discover that both SST and pH changes are caused by increased atmospheric CO_2.

7. Now show your students the false-color maps that display monthly average SST for May 1990 and May 2010. If possible, show the two maps side-by-side. Explain the key features of the maps:

- The map shows an area of the Caribbean Sea centered just northeast of Cuba and southeast of southern Florida.
- X axis = longitude, degrees west of the Prime Meridian.
- Y axis = latitude, degrees north of the Equator.
- The map is a false-color map representing ocean surface water temperature using colors. The key on the right correlates temperature values in degrees Celsius to map colors. Have students look at the numbers at the top and bottom of the color key. These show the highest and lowest data points on each map.

Discuss the following questions with your students: *Why choose May when comparing temperatures from 1990 and 2010?* May represents a month that is more or less consistently a rough average between the seasonal SST highs and lows. Comparing May-to-May should help show long-term effects. *What differences in temperature do you observe between the two maps?* Southwest of Cuba and the Dominican Republic, the water is warmer in 2010 than it was in 1990. However, northeast of Cuba, water is cooler in 2010 than it was in 1990.

8. Acidity is a measure of H+ concentration; the more free H+ ions, the lower the solution's pH and the greater the acidity. Temperature change by itself cannot add H+ ions. Where do they come from? Show your students the chemical equation:

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$

Carbon dioxide reacts with water to form carbonic acid.

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

The carbonic acid then almost instantly dissociates in the seawater, releasing the H+ ions and bicarbonate molecules.

You may demonstrate the formation of carbonic acid for your class using a container of water, blue pH indicator, and either a small piece

Video

View this demonstration at www.dataintheclassroom.org

of dry ice or a drinking straw. Use distilled water if possible as that will give you a neutral 7.0 pH to start. Add either Bromphenol blue or red cabbage indictor to the water in the container. The water will turn blue. This color will change when the acidity of the water changes. Bromphenol blue will turn yellow when the water becomes more acidic. The red cabbage indicator will turn more purplish. Observe what happens when you either add a small piece of dry ice (use safety gloves and goggles) to the container of water or blow into the water through a straw. In both cases, adding CO_2 to the water has created carbonic acid which, in solution, makes the water more acidic. If you do not want to do the demo yourself, you may show your students a video, Adding CO_2 to the Ocean, in which Dr. Jane Luchenco does the demo and discusses the impact of carbon dioxide on ocean water acidity.

9. After your class has viewed the demonstration, discuss these questions with your students: *Why do you think that the average pH of a raindrop is 5.6? Could CO_2 be responsible for falling pH in the Caribbean study area and, if so, what is that CO_2's source?* Students should understand that water in contact with Earth's atmosphere is reacting with CO_2 in the air to form carbonic acid in the raindrop and in the ocean.

10. Briefly reintroduce your students to the global carbon cycle. Use the carbon cycle diagram provided on the Teacher Master or one you might find online or in an available text. Concentrate the discussion on the carbon exchange at the ocean-atmosphere boundary. Be sure students understand the significance of this being a cycle. Discuss these questions with students: *What sources add CO_2 to Earth's atmosphere? Do you think any of these CO_2 sources has changed considerably over time?*

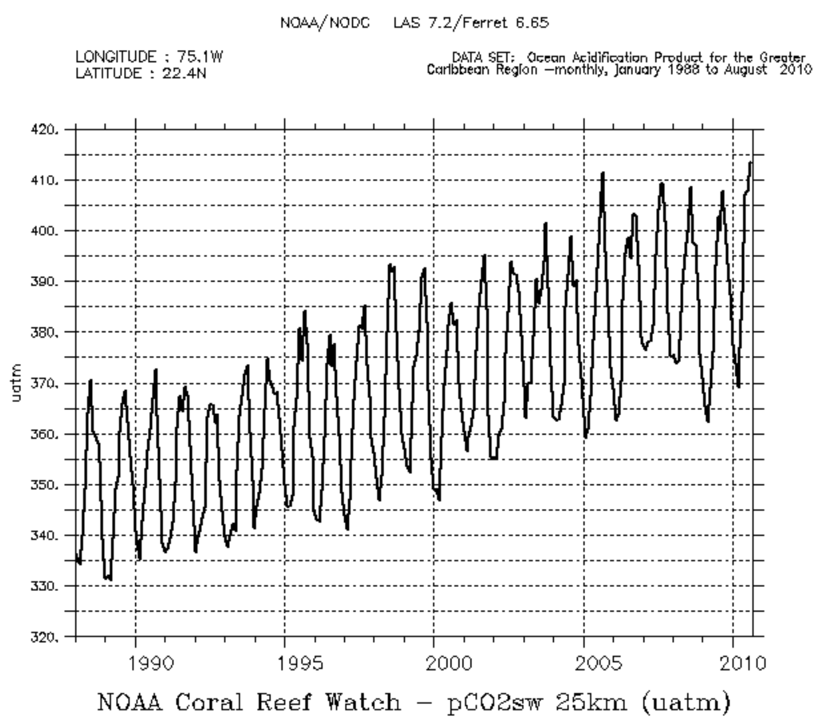
11. Give each student a copy of the Student Master, Effects of CO_2 on Ocean Acidity. If possible, go online and show students how to create the two graphs shown on the Student Master. Students will

then follow instructions on the Student Master to create a third graph for comparison. Students should use the three graphs to answer the questions on the Master:

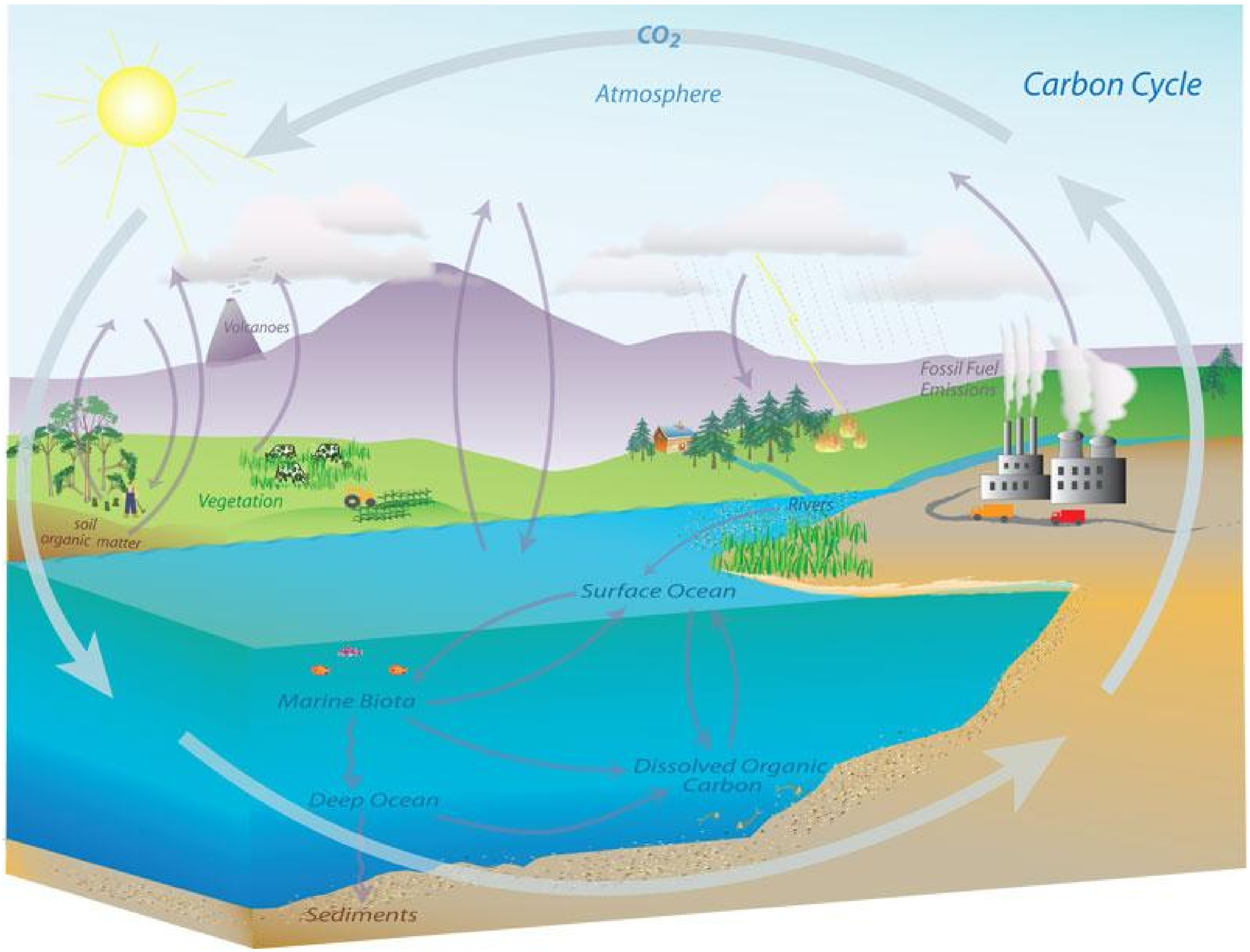
Answers:

1. pH decreases over time (i.e., water becomes more acidic).
2. Sea surface temperature increases slightly over the 20 year period.
3. pCO_2sw increases over time.
4. To increase the amount of CO_2 going into the water, you need to either lower the water's temperature and/or salinity, or increase the amount of CO_2 in the air. Globally, increased amounts of CO_2 in the air are responsible for ocean acidification.

This is the graph that students will create for the Student Master:



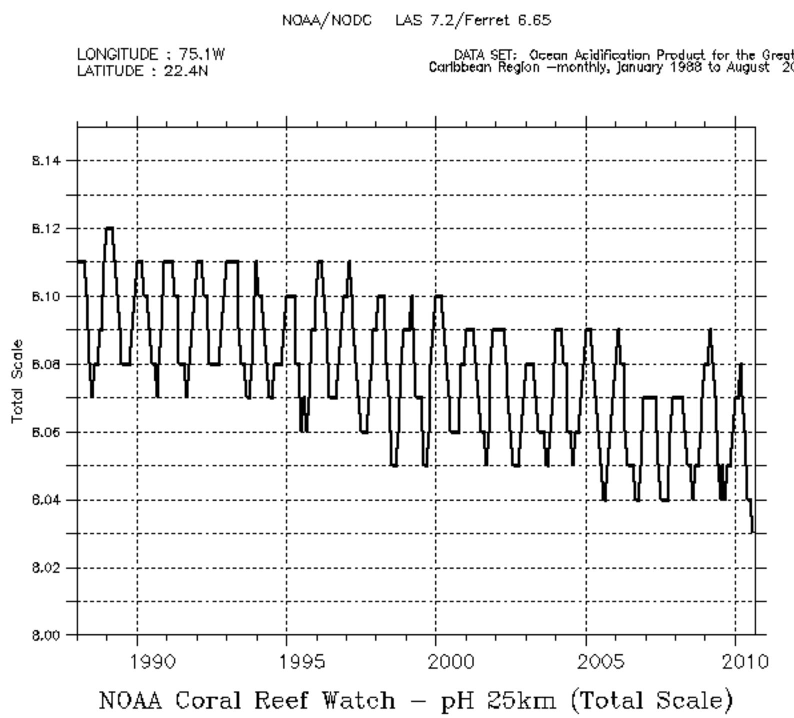
Carbon Cycle



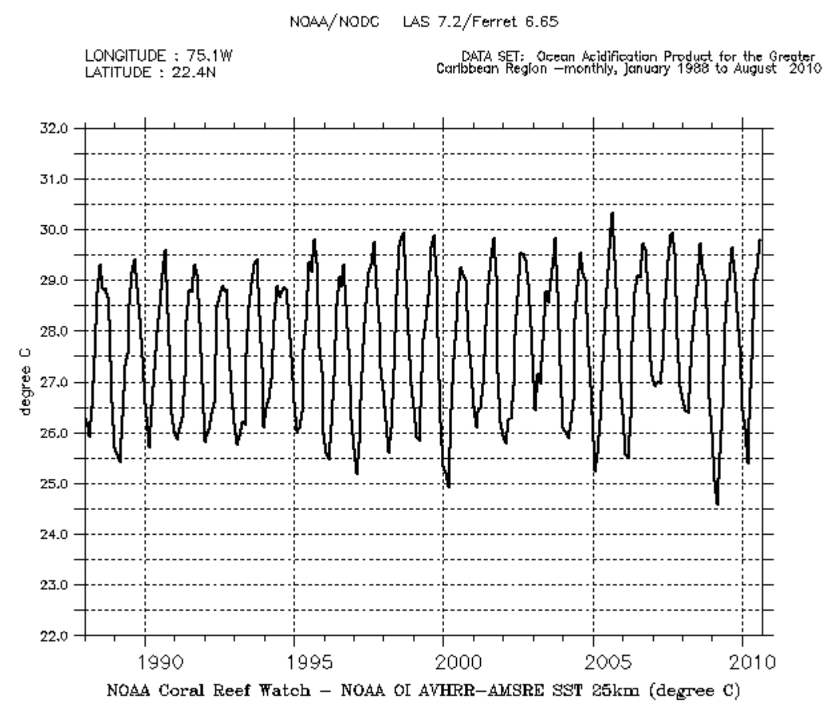
Source: NOAA

Effects of CO_2 on Ocean Acidity

Look at the pH graph below. The graph shows that surface ocean waters in the Caribbean study area have become less alkaline over the last 15 to 20 years. Comparing the pH and sea-surface temperature graphs, you might also conclude that seasonal fluctuations in sea-surface temperature have some effect on pH. If increased H+ ion concentration in the water is due to reactions between carbon dioxide in the atmosphere and water in the ocean, what would you expect to see if you graphed the amount of CO_2 dissolved in the water over time?



pH, 1988 to 2010



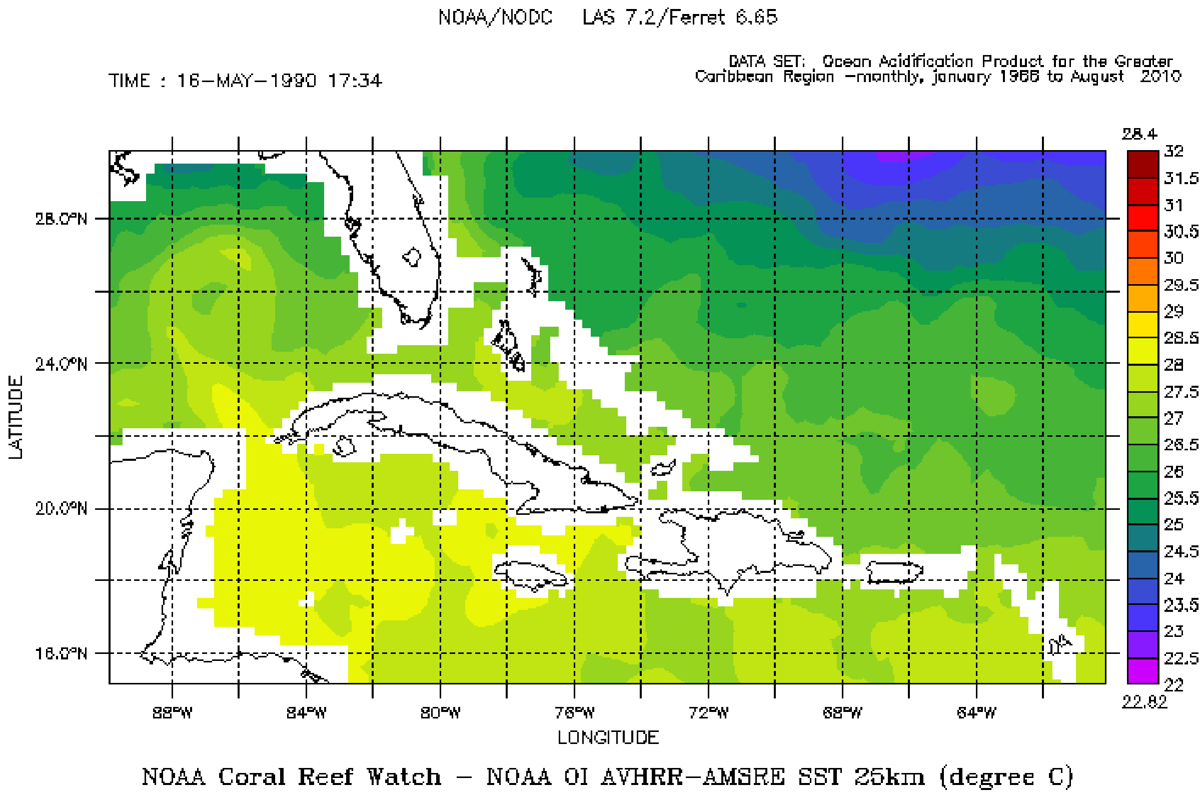
Sea-surface temperature, 1988 to 2010

For your purposes, partial pressure of carbon dioxide in sea water (pCO_2sw) can be used as an approximation of dissolved CO_2 in the water.

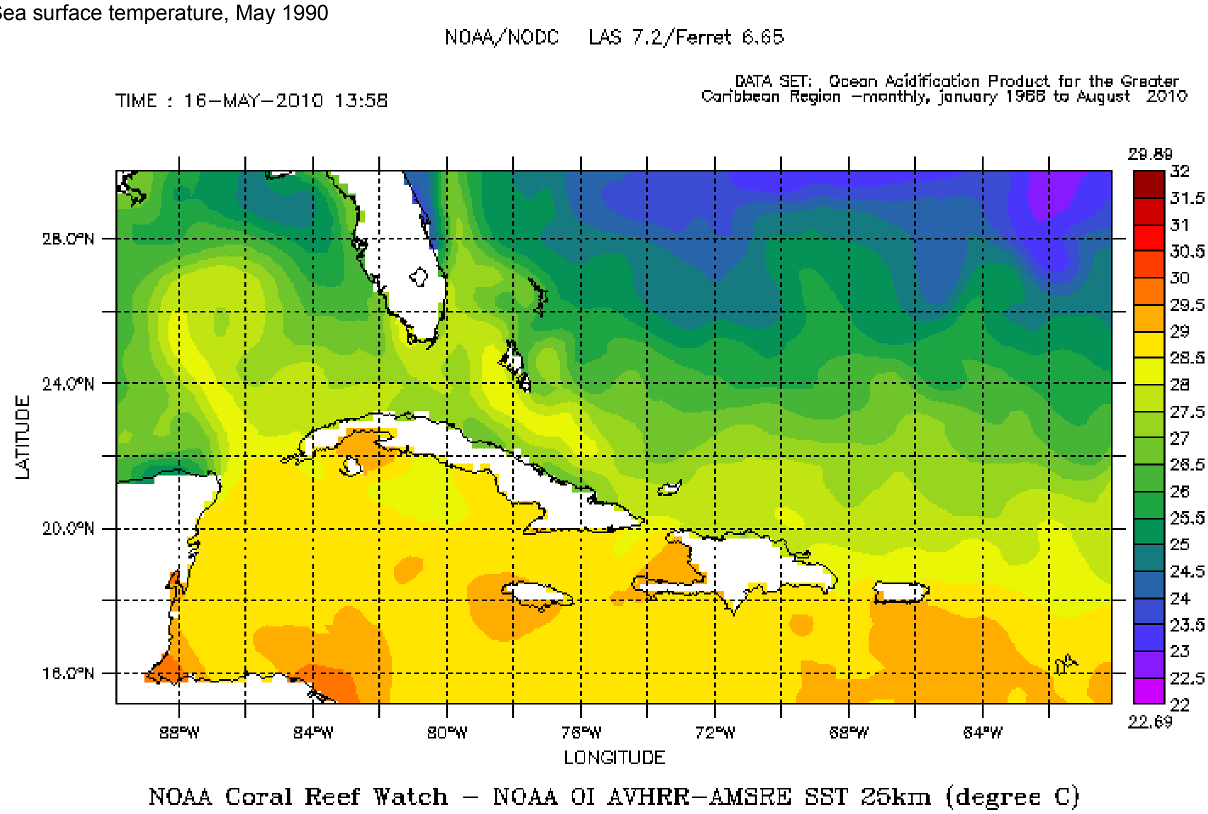
1. Visit www.dataintheclassroom.org, and find the Ocean Acidification module.
2. Follow the link to "Get Data."
3. Leave the geographic area (latitude and longitude) set to the default study area in the Caribbean Sea.
4. Select "pCO2sw" under "Which parameter?"
5. Next select "Time series graph" on the menu labeled "Which view?"
6. Change the date inputs to "January 1988" and "August 2010."
7. Click the "Get Data" button.
8. You may now save the graph to your local computer for later use. On a PC, right-click on the graph with your mouse, select "Save Image as…" and provide a file name and local save destination. On a Mac, hold down the Ctrl key and click with the mouse. If you have a printer available, you may also print the graph directly from the browser window. When you have finished saving or printing the graph, you may close that browser window.

Questions

1. Ignoring the seasonal fluctuations, describe the overall trend in pH over time.
2. Describe the overall trend in sea-surface temperature over time.
3. Describe the overall trend in pCO_2sw over time.
4. What might cause an increase in dissolved CO_2 in the ocean (and the resulting increased ocean acidity)?

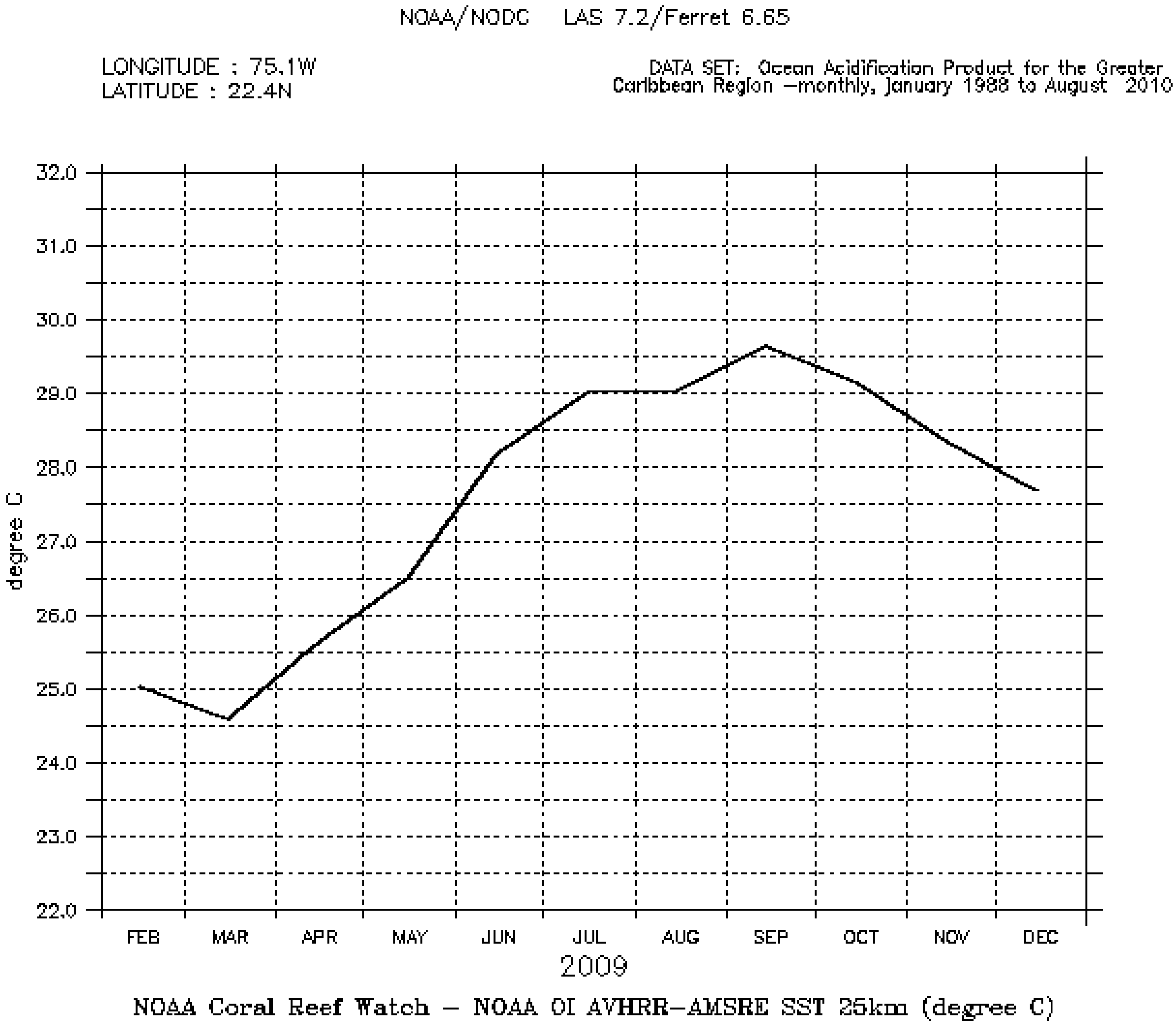


Sea surface temperature, May 1990



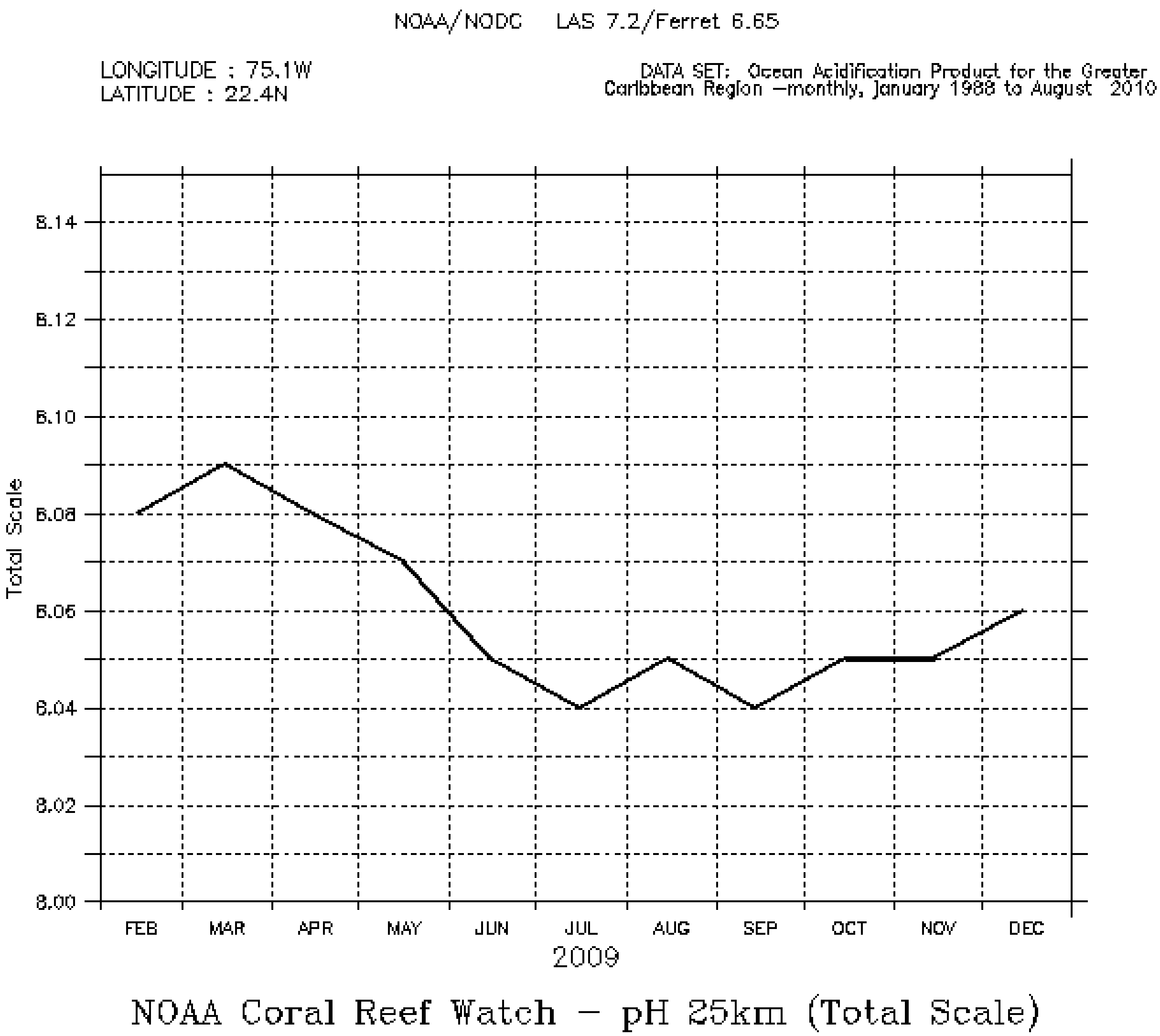
Sea surface temperature, May 2010

Teacher Master



Sea surface temperature, January – December 2009

Teacher Master



pH, January – December 2009